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*Applied Technology Associates, Inc., 1900 Randolph Rd, Albuquerque, NM 87106

14. ABSTRACT
The rapidly increasing numbers and complexity of earth-orbiting satellites in recent decades has placed heavy demands upon telemetry and ground support equipment and personnel to maintain and control the systems. A major thrust of current space program developments is the reduction of dependence upon ground control for normal satellite operations. This paper describes one such experiment currently under development at the Air Force Research Laboratory (AFRL), which addresses these needs. The experiment combines an optical polarimeter for measurement of multi-spectral polarization signals of orbiting objects and a system of intelligent software agents, which will provide automated payload and bus control. We discuss the development of the optical system hardware, software agent development, and aspects of the processing and control of information from on-board data.

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INTELLIGENT OPTICAL POLARIMETRY DEVELOPMENT FOR SPACE SURVEILLANCE MISSIONS

Lenore McMackin, Paul Zetocha, Clint Sparkman

Air Force Research Laboratory, Space Sensing and Vehicle Control Branch
AFRL/VSSS, Kirtland AFB, NM 87117 USA
Phone: (505) 853-4114 Fax: (505) 846-6053 Email: zetocha@plk.af.mil

Harold McIntire, Matthew Fetrow, Kenneth Bishop

Applied Technology Associates, Inc
1900 Randolph Rd., Albuquerque, NM 87106
Phone: (505) 846-6110 Fax: (505) 846-6132 Email: fetrow@ataway.aptec.com

ABSTRACT

The rapidly increasing numbers and complexity of earth-orbiting satellites in recent decades has placed heavy demands upon telemetry and ground support equipment and personnel to maintain and control the systems. A major thrust of current space program developments is the reduction of dependence upon ground control for normal satellite operations. This paper describes one such experiment currently under development at the Air Force Research Laboratory (AFRL) which addresses these needs. The experiment combines an optical polarimeter for measurement of multi-spectral polarization signals of orbiting objects and a system of intelligent software agents which will provide automated payload and bus control. We discuss the development of the optical system hardware, software agent development, and aspects of the processing and control of information from on-board data.

1. INTRODUCTION

Intelligent satellite systems have the potential to transform space-based surveillance and scientific missions from the current ground-based, manpower-intensive approach to fully autonomous satellite systems capable of independent data acquisition, system control, and data processing, on-board cueing and mission reconfiguration, selective dissemination of information to users, and anomaly detection and correction. These systems will be able to acquire and process data and use information extracted from that data to control on-board systems such as attitude and orbital position, or to cue other space or ground systems automatically. Autonomous systems would find immediate use in a multitude of applications involving space-based surveillance of both space and ground objects.

This paper addresses technological challenges of constructing and deploying an intelligent space-based target cueing device that operates on principles of optical polarimetry, processes data on board using smart sensing technology, and is guided autonomously by intelligent software agents. Specifically, we aim to apply previous and current basic research in material and shape characterization based on low spatial resolution polarization signals typical of small polarization imaging systems to the design of an intelligent space polarimeter. We will do this by adapting a four-channel polarimeter already in use at the Air Force Research Laboratory (AFRL) to a space platform such as the MightySat II.2 satellite while controlling data acquisition, smart polarization state processing, target detection and cueing signal generation tasks using intelligent agent software architectures.

The ultimate aim of the proposed work is to produce a small, lightweight, inexpensive cueing device that can narrow the potential field for more data intensive surveillance systems saving time, unnecessary computation and bandwidth. This paper will discuss automated control systems for a protoype space polarimetry experiment and how an optical payload interfaces with other pertinent satellite subsystems. Subsystem models used in the prototype include components of the attitude control, propulsion, and sensor payload will then be described along with their interrelationship and a description of the collaboration mechanisms used. Various simulation scenarios are

currently being devised to exercise the prototype system. Descriptions of these simulations will then be given. This will include descriptions of the various AI modules used and the benefits to the overall reasoning process that resulted. Our results will be discussed in the context of the most likely operational role for polarimetry in space.

We will begin with a discussion of the fundamentals of optical polarimetry. An overview of the intelligent agent architecture and the framework used for intelligent polarimetric data processing is then given. The autonomous planning capability will then be described and results from its incorporation into the agent architecture will be highlighted. The paper will then summarize the strengths and weaknesses of the agent approach to the enhancement of on-board spacecraft autonomy. Lastly the paper will conclude with a summary of our future plans for this prototype system.

2. POLARIMETRY

The polarization of reflected and emitted optical radiation is highly dependent on material properties and is also influenced by orientation and surface roughness. Measurement of polarization can therefore be expected to yield additional information about target surfaces features, shape and configuration without necessarily requiring high spatial resolution, greatly simplifying space optical systems.

The polarization state of an electromagnetic wave is fully described by a set of 4 parameters known as the Stokes parameters. Collectively, these parameters comprise the Stokes vector.

$$\mathbf{S} = \{S0, S1, S2, S3\} \tag{1}$$

Measurement of the polarization is typically performed by measuring four basic intensity values: I_0, the intensity of all polarization states; I_1, horizontal linear polarization, I_2, polarization at $+45^o$, and I_3, the right circular polarization component. Each of these is measured by filtering the incident light. These intensity values are converted to the Stoke's vector parameters by a simple linear combination of these intensity measurements,

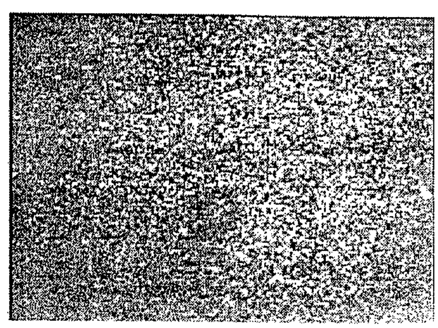
$$\begin{aligned} S_0 &= 2I_0 \\ S_1 &= 2I_1 - 2I_0 \\ S_2 &= 2I_2 - 2I_0 \\ S_3 &= 2I_3 - I_0 . \end{aligned} \tag{2}$$

From the Stokes components, the degree of polarization may be computed using simple math,

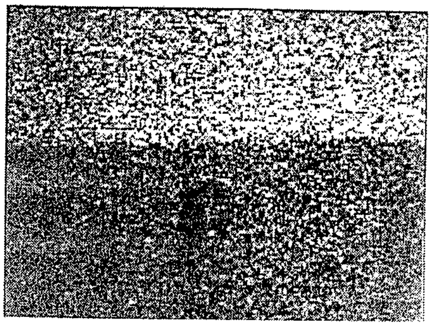
$$DoP = \frac{\sqrt{S_1^2 + S_2^2 + S_3^2}}{S_0} \tag{3}$$

Visible and IR polarimetry may provide improvements in the ability to distinguish targets from natural backgrounds due to sharply contrasting polarization signatures of man-made and natural materials. The figure below illustrates the ability of polarization to distinguish between visually similar materials. When imaged in linearly polarized light white-painted aluminum is virtually indistinguishable from white paper. However, when illuminated with circularly polarized light the distinction between the materials becomes clear.

In addition, the retardance, which is a measure of the phase difference between two orthogonal polarization components of the light, has been shown to discriminate between metallic and dielectric materials in machine vision applications [1]. Figure 1 is not an image in the traditional sense of intensity but is a "pseudo image" visualization of the calculated polarization states of each pixel. It should be noted that the quality of polarization pseudo images is not highly dependent on the contrast ratio of the intensity measurement and much information can be obtained even from low signal to noise measurements.



(a)



(b)

Fig. 1. (a) In linear polarization it is visually difficult to discriminate white paint from paper. (b) Active illumination with and detection of circular polarization component, S3, easily reveals the different materials. The top half of each image is painted, the bottom half is paper.

The primary objective of our polarimeter will be to collect polarization signals from targets that are not necessarily spatially resolved. Analysis of the signal data will be used to evaluate the use of polarization for detecting, classifying and identifying optically unresolved objects from autonomously operating space platforms.While the polarimetry data and analysis results are expected to be of scientific interest in their own right, the principal purpose of the experiment is to demonstrate the use of intelligent agents for mission autonomy in space. For mission autonomy to be feasible optical systems must operate autonomously, acquiring data, calculating polarization vectors for each pixel, detecting possible targets based on the signals and utilizing target information to reconfigure or cue other satellite subsystems. Therefore, optical systems must be interfaced with other satellite functions such as attitude control and orbit control systems to achieve mission autonomy. The use of intelligent agents to control optical data acquisition and processing will be demonstrated.

3. INTELLIGENT AGENTS

The majority of approaches to satellite autonomy are piecemeal with specific techniques applied to given activities. Decision making is generally based on information from a subset of the total information available and generally does not take into account the status of other components and mission objectives. In reality much of the functionality on board a satellite has a high degree of interdependence and truly intelligent decision making should account for all of these aspects. Intelligent agents offer a mechanism to integrate these various components. Agent-based systems are goal-oriented systems in which individual agents are assigned specific tasks and in which larger problems are solved by having a suite of agents operating in cooperation with each other. Agents collaborate through what are known as *blackboards* or *message centers* [2][3].

Consider how an agent-based system might function for a surveillance satellite mission. With regards to the payload itself, there might be agents which control the mirror positioning, control the taking of images, and agents which perform a pattern recognition function. Mirror control is a function of the output of the pattern recognition agents. Based on the results of these agents it may be desirable to reorient or maneuver the spacecraft. If a maneuver is desired several additional agents come into play. For a maneuver to occur several tasks need to happen, which includes determination of the desired end orbital elements of the spacecraft, maintenance of attitude during maneuver, appropriate heating and temperature maintenance of the catalyst bed thruster heaters, and thruster firing. Within each of these areas any number of subtasks need to happen. These tasks can be represented as agents and collaboration between agents can take place through agent message centers. A system could be designed so that all agent communication takes place through a single agent message center, however it is easy to see that for reasons involving complexity and speed this is less than desirable for large systems. A better approach would be to have a hierarchy of agents where communication between agents can be kept local when necessary while still allowing for communication between any two agents when appropriate. For instance, the picture below depicts a hierarchical system where communication between agents in the ACS, propulsion, thermal, or Command and Data handling subsystems are through localized agent message centers. When any of these agents needs to collaborate amongst each other this is done through a top level message center. The figure below depicts a setup which may exist on-board one satellite. This naturally extends to a constellation of satellites. Similarly equipped satellites might communicate with each other through an additional higher level agent message center. This is also how ground-based agents would communicate with on-board agents. This idea of a hierarchy of agents has some analogy with object oriented systems. Agents can also have the ability to inherent skills from parent agents in their hierarchy.

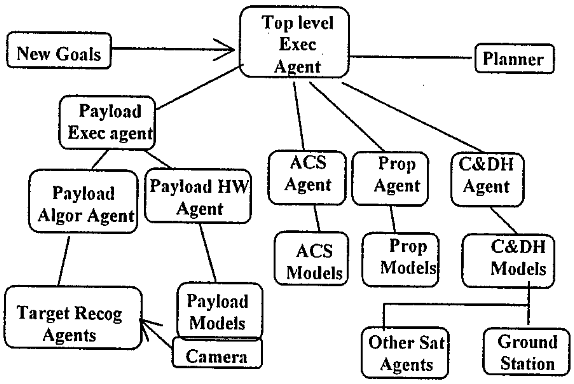


Figure 2: Agent Hierarchy

We are developing an on-board agent based architecture for intelligent satellite processing and control. The prototype agent architecture is being developed in MATLAB under Windows NT, with appropriate subsystem models also developed in that language. Subsequent development will port this architecture to C++ and a real-time flight processor. To assist in the reasoning process the architecture is equipped with a number of Artificial Intelligence (AI) modules which include neural networks, an expert system, and a model-based mechanism to perform satellite fault detection, isolation, and resolution (FDIR). Figure 3 depicts our agent architecture. The basic element in our architecture is the *skill*. A *skill* is basically any task or set of tasks which would need to be accomplished. Agents are made up of skills encapsulated in a natural language. These agents then communicate with each other through an agent message center by registering themselves and their skills (i.e., capabilities).

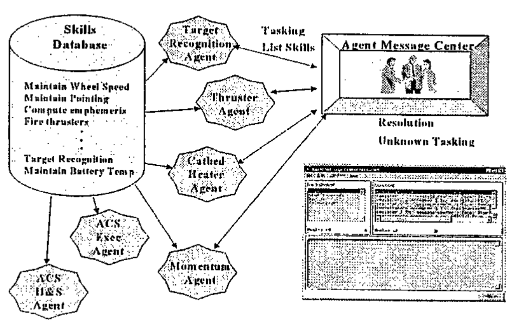


Figure 3: Agent Architecture

As a first prototype of our architecture we are applying intelligent agents to the problem of autonomous control of a space-based polarimeter. The prototype is being developed and will be simulated in an in-house testbed which is currently under development. In our prototype environment all polarimetric processing, including stokes vector and degree of polarization calculations, is done within Matlab. The majority of the processing will be treated as a set of skills for use by the agents. Related to the payload, agents are being developed which will request an image to be taken, calculate the stokes vector, calculate and retrieve the degree of polarization, determine the polarization signature of an image on a pixel-by-pixel basis, generate a cueing signal, and control the pointing of a gimbaled mirror. The cueing signal is basically target/background information and contains information regarding the pixels in the image which contain target information. Mirror control tasking by the agents is a function of the cueing signal.

External to the payload agents we are developing agents in other subsystems for which the polarimeter has dependence upon. For instance it may be desirable to reorient the spacecraft due to a request to take a picture of an area which is currently not viewable within the current constraints of the gimbaled mirror. Agents are being developed which maintain, control and reorient spacecraft attitude along with all spacecraft activities associated with performing those functions.

Our initial prototype will make only limited use of the AI tools available within the architecture. identification. For target detection The initial focus is on target detection as opposed to the much more difficult problem of target we will make limited use of the expert system. Subsequent development will utilize more fully our AI tools.

3. CONCLUSION

Our research to date in the use of intelligent agents for on-board processing and control is still very preliminary, however the technology appears very processing. Much more work still needs to be done in order to access the true viability of the use of this technology in order to enhance spacecraft autonomy. Our architecture offers the potential for greater autonomy, with its integrated AI tools, modular and extensible design, and natural language capability. In addition we are developing a backend to our Matlab environment which will map our architecture to C++ in a real-time flight environment. We are also currently developing an autonomous planner which will take high level goals and perform system reconfiguration in response to changing mission requirements or contingencies.

4. REFERENCES

1. H. Chen and L. B. Wolff, "Polarization phase-based method for material classification in computer vision," Int'l. Journal of Computer Vision 28(1), 73-83 (1998).

2. Dan R. Ballard, "Intelligent Agents and Agent Communication Languages for Mission Operations", Final Report for NASA contract NAS5-33264, June 1996.

3. Barney Pell, Erann Gat, Ron Keesing, Nicola Muscettola, Ben Smith, "Robust Periodic Planning and Execution for Autonomous Spacecraft", Proceedings of the International Joint Conference on Artificial Intelligence", 1997.